receptor-binding domain of the spike protein that has an attached carbohydrate molecule. This region is not part of the key area that directly binds to ACE2. The site that S309 recognizes is evolutionarily conserved in spike proteins across a range of bat coronaviruses (in the genus *Betacoronavirus* lineage B; subgenus *Sarbecovirus*) that have similarities to the SARS-like coronaviruses. This raises the possibility that such an antibody could have wide applicability in tackling related viruses. Not only, then, is this antibody of interest when investigating ways to manage the COVID-19 pandemic in the years ahead, but it might also be considered for use in preventing future outbreaks of related animal viruses, if they make the leap to causing infection in humans.

Ultimately, it seems unlikely that a robust treatment for COVID-19 will rely on a single antibody. Rather, as was the case for SARS, a synergistic approach combining different monoclonal antibodies in an antibody cocktail might be more effective[5]. For such approaches to move forwards, evidence of effective antibody neutralization from *in vitro* studies will be needed, along with *in vivo* data assessing how well an antibody can boost other aspects of the immune response — by enlisting other immune cells to tackle the infection, for example. There are many promising avenues to explore in these efforts.

Pinto and colleagues got a head start with their work by exploring pre-existing antibodies, and they should now have more B-cell populations to mine. Many other teams, to give just some examples[2,6–13], have also presented useful discoveries in the hunt for antibodies that can target SARS-CoV-2. The next steps will be to test individual antibodies and antibody cocktails in animal models, to determine whether they offer protection, and then to assess their safety and effectiveness in human clinical trials. An accelerated path might narrow the time lag between antibody discovery and proof-of-concept trials in humans to as little as five or six months[14].

The most recent prominent example of immunotherapy for infectious disease relates to battling the Ebola virus. In concert with vaccines and conventional, small-molecule-drug trials, the development of monoclonal-antibody therapies for Ebola has progressed rapidly. Cocktails of antibodies, beginning with one called ZMapp, that target a key Ebola viral protein called GP in two crucial regions of the protein, are continuing to be developed[15–17]. This progress in efforts to tackle Ebola gives hope for similar immunotherapy achievements in targeting SARS-CoV-2. Pinto and colleagues' work marks a major step towards that much-anticipated, and much-needed, success.

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Environmental science

Atmospheric CO_2 removed by rock weathering

Johannes Lehmann & Angela Possinger

Large-scale removal of carbon dioxide from the atmosphere might be achieved through enhanced rock weathering. It now seems that this approach is as promising as other strategies, in terms of cost and CO_2-removal potential. **See p.242**

Achieving targets for mitigating global warming will require the large-scale withdrawal of carbon dioxide from the atmosphere. On page 242, Beerling *et al.*[1] report that enhanced rock weathering in soils has substantial technical and economic potential as a global strategy for removing atmospheric CO_2. When crushed basalt or other silicate material is added to soil, it slowly dissolves and reacts with CO_2 to form carbonates. These either remain in the soil or move towards the oceans. The authors argue that this method would enable between 0.5 billion and 2 billion tonnes of CO_2 to be removed from the atmosphere each year. This rate is similar to that of other land-based approaches[2], such as the accrual of organic carbon in soil, carbon capture and sequestration in geological formations, and the addition of biochar (a carbon-rich material) to soil.

Beerling and colleagues find that removing atmospheric CO_2 through enhanced rock weathering would cost, on average, US\$160–190 per tonne of CO_2 in the United States, Canada and Europe, and \$55–120 per tonne of CO_2 in China, India, Mexico, Indonesia and Brazil. Furthermore, the authors report that China, the United States and India — the three largest emitters of CO_2 from fossil-fuel use — have the highest potential for CO_2 removal using this method. However, they also note that the application of silicate material to soil (Fig. 1) requires careful assessment of the risks, such as the possible release of metals and persistent organic compounds (compounds resistant to environmental degradation).

Despite the enthusiasm the authors' findings might generate, it is crucial to stress that, even under optimistic assumptions, enhanced rock weathering will sequester only some of the annual global carbon emissions from fossil-fuel use. Therefore, reducing these emissions should still be the top priority for averting dangerous climate change. But, as Beerling *et al.* note, any approach is insufficient alone, and should be considered as part of a portfolio of options.

Several other land-based carbon-sequestration techniques rely on soils. However, inorganic-carbon sequestration by rock weathering is fundamentally different from organic-carbon sequestration. The latter relies on photosynthesis by plants to remove CO_2 from the atmosphere, and on soils to retain the plant carbon, mostly in the form of microbial remains. In the future, therefore, scientists should pay closer attention to what they mean by 'carbon sequestration' — is it inorganic or organic?

The sequestration of atmospheric CO_2 through enhanced rock weathering shares some of the principal appeal, but also the challenges, of organic-carbon sequestration. The fact that crop production benefits is certainly a key asset of both methods. In the

Figure 1 | Application of silicate material to cropland. Beerling *et al.*[1] demonstrate that enhanced rock weathering, achieved by adding crushed basalt or other silicate material to soil, is an effective strategy for removing carbon dioxide from the atmosphere.

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case of enhanced rock weathering, the added rock contains essential plant nutrients, such as calcium and magnesium, as well as potassium and micronutrients that promote crop production in several ways. We would go even further than the authors do, to claim that these nutrients are currently insufficiently supplied in agriculture.

Increasing soil pH alone would substantially boost crop yields in many regions of the world, because it is possible that low pH constrains crop production on more than 200 million hectares of arable and orchard soils[3]. This area is equivalent to about 20% of the total extent of these soils (967 million hectares; see go.nature.com/31rcajd). Consequently, on a global scale, acidity is the most important soil constraint for agriculture[4]. However, there have been no detailed multi-regional analyses of the difference in crop yield between low-pH and optimum-pH soils, and such investigations would benefit the study of synergies between carbon-sequestration methods. The proposed rock additions could conceivably mitigate the low use and supply shortages of agricultural limestone in several regions[5]. Furthermore, calcium improves root growth in acidic subsurface soil[6], with crucial knock-on effects through greater water uptake by plant roots.

Co-deployment of enhanced rock weathering with other soil-based sequestration approaches might both reduce limitations and maximize synergies[7]. Beerling and colleagues' study hints at some of these opportunities and at constraints that have procedural and soil-biogeochemical aspects. Greater crop growth will increase the input of crop residue (the materials from crops that are left in a field after harvesting) to the soil, and thereby enhance the accrual of organic carbon. However, the possibility that interactions between calcium and organic matter impede the return of CO_2 to the atmosphere has been sparsely explored, and there is little information on the effects of magnesium. In principle, calcium can reduce the decomposition of organic matter by facilitating adsorption to clay, inclusion in carbonates or aggregation[8]. But the indirect effects of calcium through changes in microbial ecology or interactions with organic compounds, rather than interactions only between organic compounds and clay minerals, are rarely studied.

If the synergy becomes a trade-off between organic-carbon sequestration and crop production, the organic-carbon content of soil could decrease, threatening the livelihoods of farmers, and even food security. Any carbon sequestration involving soils is a formidable challenge to incentivize, predict and monitor[9], because the sequestration technologies must be used on vast areas of land that are operated by hundreds of millions of farmers. Inevitably, there will be individual cases in which positive-yield projections are not met or crop yields even decrease, where incentives fail to persuade farmers, or where supply chains break down. But scientists should not be deterred from evaluating such technologies, and should instead accept that farmers need to be in the driving seat in adapting soil management to meet their specific site and crop-production goals. A concerted global effort will be required to develop site-specific optimization through farmer-centred research.

Fertilizer distribution networks are common in many parts of the world. But even where these networks are in place, success in the adoption of enhanced rock weathering might not rely on its crop-production benefits alone. We posit that carbon markets are required, and that it would be helpful if they incentivized socially and environmentally sound implementation[10]. For technologies to be eligible, it must be shown that they provide extra incentives for adoption (additionality), beyond what increased soil fertility would deliver. We emphasize that implementation of enhanced rock weathering and other soil-based carbon sequestration must consider equitable and financially sound incentives for farmers that overcome challenges of additionality, among others[10], in a proactive way.

> **"China, the United States and India have the highest potential for CO_2 removal using this method."**

Consequently, the main lesson here might be that several of the major potential technologies for removing atmospheric CO_2 could generate substantial benefits for food production, and are centred around managing soils. Farmers must be fully behind such a global effort or it will fail. Scientists might need to recognize that climate-change mitigation is not a sufficient incentive on its own, and that benefits to crop growth will need to be prioritized, as will financial incentives. Such an approach of financially supporting soil health and crop production could emerge as our best near-term solution to the problem of removing CO_2 from the atmosphere.

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